CRITICALITY EXPERIMENTS ON U-H_2O LATTICES WITH 19.75% ENRICHED UZrCN FUEL

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ABSTRACT

Criticality experiments on U-H2O lattices with LEU fuel rods were performed using "Giacint" critical facility of the Joint Institute for Power and Nuclear Research – Sosny of the National Academy of Science of Belarus. Three configurations of critical assemblies were studied, two of which had an annular cores. The fuel rod pitch is 32 mm with a triangular grid. The fuel composition – UZrCN with 19.75% uranium-235 enrichment. The absorber composition – B_4C. The clad material of fuel and absorber rods is stainless steel. The moderator and reflector – H_2O. The criticality conditions obtained by adjusting the water moderator height in the studied lattices. Subcriticality of these assemblies was also measured when one or group of the absorbing rods were inserted into the core or the water moderator was drained below the critical level. The inverse kinetic method was used to measure subcriticality. The results of experiments on critical assemblies have been analyzed by creating detailed calculation models and performing simulations for the experiments. The analyses used the MCNP-4C and MCU-PD computer programs. This paper presents the obtained experimental and analytical results.

1. Introduction

This paper presents the experimental and analytical parameters of criticality of the uranium-water critical assembly W-20-2-0, W-20-2-1 and W-20-2-2 with a core based on 19.75% fuel rods.

The experiments were performed using the "Giacint" critical facility of the Joint Institute for Power and Nuclear Research – Sosny (JIPNR-Sosny) of the National Academy of Sciences of Belarus [1]. The experimental results were analyzed in order to estimate whether they can be used as benchmark criticality data.

2. Critical assemblies

Each critical assembly represented hexagonally pitched (32,0 mm) lattice of rods with UZrCN (19.75% enrichment by uranium-235) in steel clad with a water reflector and moderator. The critical assembly is a thermal "open tank" critical assembly, comprising the core, the side reflector, the upper and lower end reflectors, and actuating devices (ADs) of the control and protection system (CPS). The general view of the critical assemblies W-20-2-0, W-20-2-1 and W-20-2-2 shown in the Figures 1, 2 and 3.

The uranium-water critical assembly is located in the critical assembly's tank, which represents a welded stainless steel structure 2020 mm high and 1810 mm in diameter. The tank has a top flange to fix the aluminum hoods of the neutron detectors. The core of the critical assembly comprises fuel and absorbing rods, which are fixed in the spacing hexagonal grids from 10-mm aluminum alloy with holes arranged in the hexagonal grid with the pitch of 32 mm and supported by the hexagonal plate from stainless steel, 16 mm thick, with holes for the control and protection system's controls. A hexagonal upper plate from 16-mm stainless steel is arranged above the fuel rod pitch; the plate also has holes arranged in the hexagonal grid with the pitch equal to the pitch of holes in the spacing grids. The spacing grids are arranged along the upper (bottom of the grid) and lower (top of the grid) edges of the core. The support plate is arranged ~800 mm from the bottom of the critical assembly's tank.

The side water reflector has tight hoods, around the core, with neutron detectors of the control and protection system, which are fixed to the flange of the critical assembly's tank.

3. Elements of the core

Loading charts of uranium-water critical assemblies W-20-2-0, W-20-2-1 and W-20-2-2 shown in Figure 4.

The fuel rod (Fig. 5) comprises a fuel section, a cladding and end pieces. The fuel section comprises cylindrical tablets, 10,75 mm in diameter, from uranium-zirconium carbonitride $U_{0,9}Zr_{0,1}C_{0,5}N_{0,5}$. The overall length of the fuel section is 500 mm. The gaps between the fuel section tablets and the fuel rod cladding have a gas helium medium at 0,11 – 0,12 MPa. The overall length of the fuel rods is 620 mm.

The lower end piece of the fuel rod comprises a lower plugs, a spring, gaskets and a pin. The upper end piece of the fuel rod comprises an upper plug. The fuel rod cladding is made from a tube with the 12 mm outer diameter and the 0,6 mm thick wall.

Each critical assembly has six CPS ADs (two emergency protection ADs designated as EP, two compensating reactivity ADs designated as CR and two manual regulation ADs designated as MR), evenly placed on two belts:
– the first belt includes ADs designated as EP-1, EP-2 and CR-1;
– the second belt includes: compensating ADs CR-2, manual ADs designated as MR-1 and MR-2.
Table 1 shows the composition of CPS ADs of the critical assemblies.

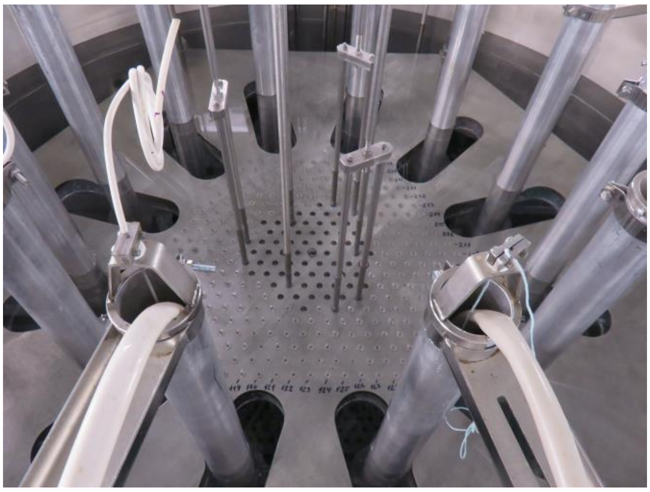

Fig 1. The critical assembly W-20-2-0

Fig 2. The critical assembly W-20-2-1

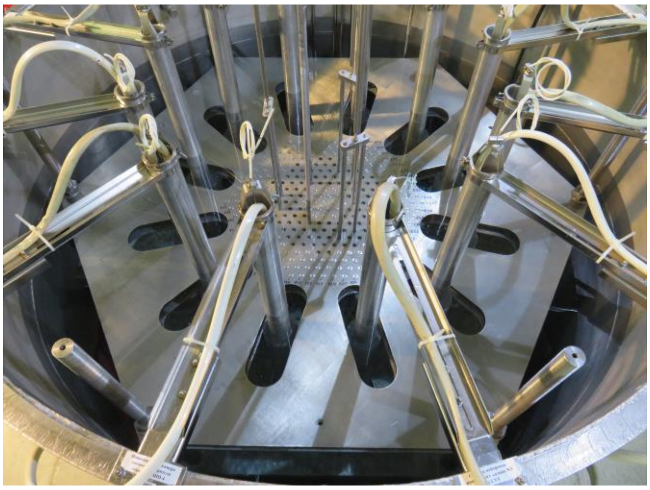

Fig 3. The critical assembly W-20-2-2

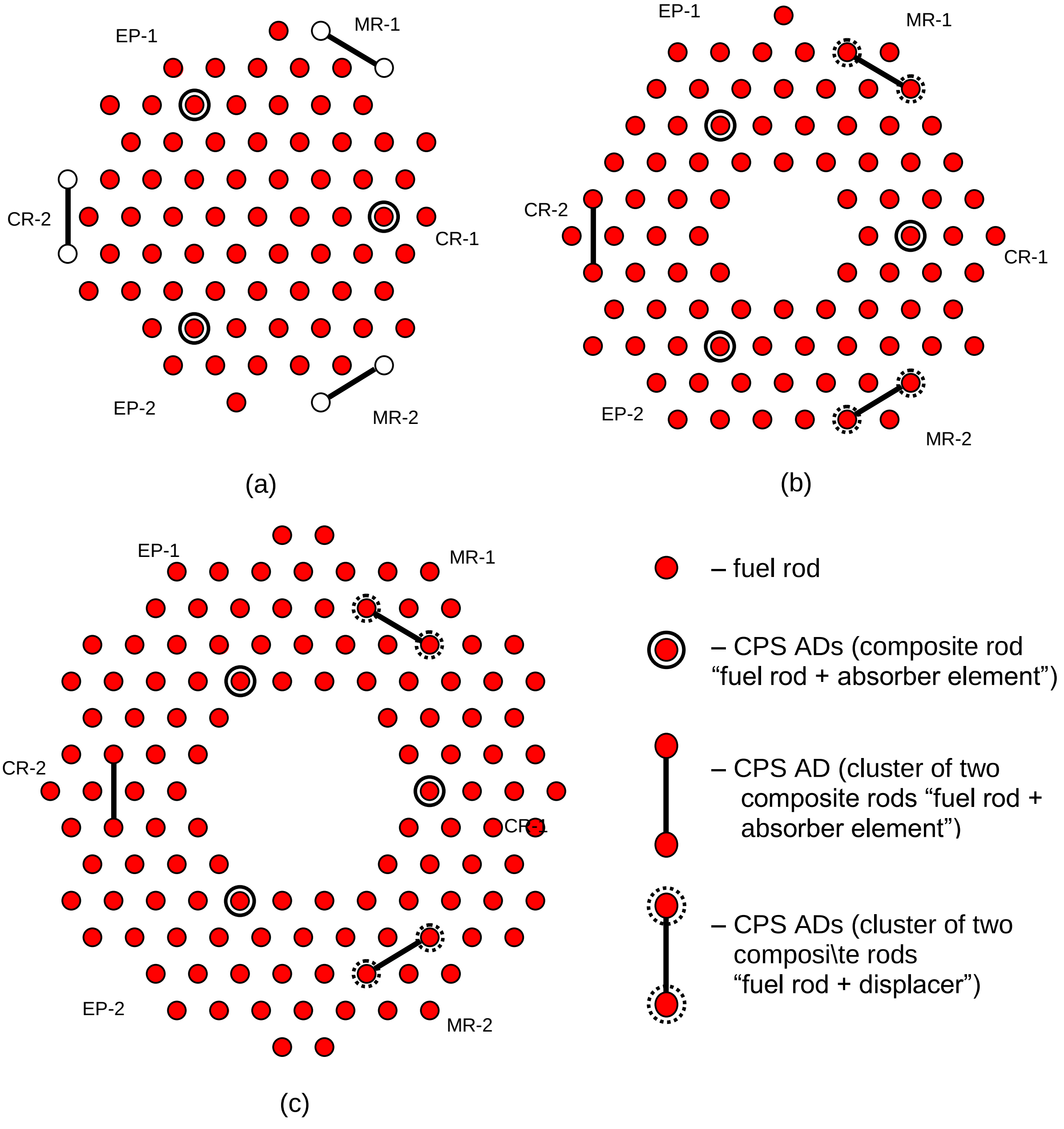

Fig 4. Loading charts for the critical assemblies W-20-2 (a), W-20-2-conf1 (b) and W-20-2-conf12(c)

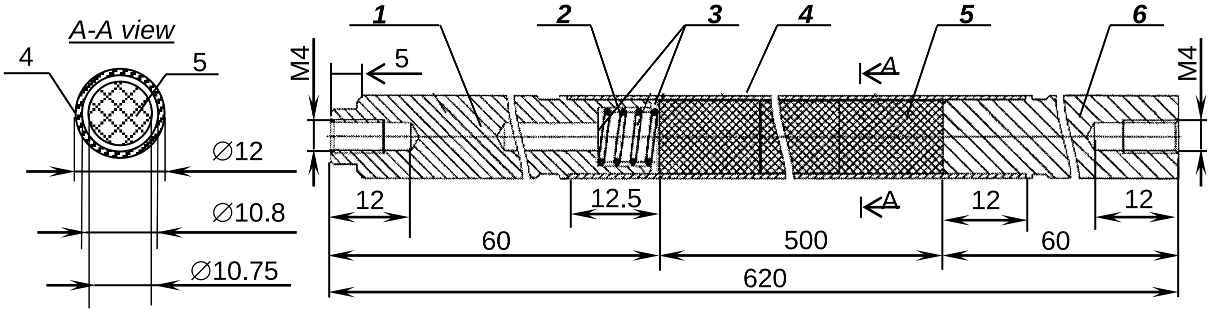

Fig 5. Fuel rod:
1 – lower plug; 2 – spring; 3 – gaskets; 4 – casing; 5 – fuel core; 6 –

Critical assembly	Lattice pitch	CPS AD	AD's elements
W-20-2-0	32 mm	AD EP-1	composite rod (fuel rod + absorber element)
		AD EP-2	composite rod (fuel rod + absorber element)
		AD CR-1	composite rod (fuel rod + absorber element)
		AD CR-2	cluster of two composite rods (plexiglas tip + absorber element)
		AD MR-1	cluster of two composite rods (plexiglas tip + absorber element)
		AD MR-2	cluster of two composite rods (plexiglas tip + absorber element)
W-20-2-1, W-20-2-2	32 mm	AD EP-1	composite rod (fuel rod + absorber element)
		AD EP-2	composite rod (fuel rod + absorber element)
		AD CR-1	composite rod (fuel rod + absorber element)
		AD CR-2	cluster of two composite rods (fuel rod + absorber element)
		AD MR-1	cluster of two composite rods (fuel rod + displacer)
		AD MR-2	cluster of two composite rods (fuel rod + displacer)

Tab 1: Composition of the CPS ADs of critical assemblies W-20-2-0, W-20-2-1 and W-20-2-2

Composite CPS rod "fuel rod + absorber element" consist of fuel rod and absorber element joined among themselves by the steel rod in 12 mm diameter and 80 mm length so that the distance between a fuel rod core and boron carbide makes 200 mm.

Absorber element is a cylindrical casing with 12 mm diameter and 1 mm walls, upper and lower shanks with 10 mm diameter and 60 mm length and boron carbide filling density 1,38 g/cm3, the filling height is 500 mm. The absorber element is tight. The total absorber element length is 620 mm.

Composite CPS rod "plexiglas tip + absorber element" consist of plexiglas tip with 10 mm diameter and 632 mm length) and absorber element joined among themselves by the steel rod in 12 mm diameter and 80 mm length so that the distance between a plexiglas and boron carbide makes 120 mm.

Composite CPS rod “fuel rod + displacer” consist of fuel rod and displacer joined among themselves by the steel rod in 12 mm diameter and 80 mm length so that the distance between a fuel rod core and air of displacer makes 200 mm.

Displacer is a cylindrical casing with 12 mm diameter and 1 mm walls, upper and lower shanks with 10 mm diameter and 60 mm length and air, the filling height is 500 mm. The displacer is tight. The total displacer length is 620 mm.

4. Neutron physical parameters of the uranium-water critical assembly

Tables 2, 3 and 4 represent results of measurement of reactivity effects on the critical assemblies W-20-2-0, W-20-2-1 and W-20-2-2. The confidence interval of all experimental values of reactivity are given for a confidence probability 0.68.

CPS ADs position, mm	Fuel rods, pcs.	Water level*, mm	Water tempe-rature, °C	Reactivity, β_{eff}
EP-1=EP-2=0; CR-1=CR-2=0; MR-1=MR-2=0	67	498.2±1.0	11.8±0.1	0.000 ± 0,001
EP-1=EP-2=0; CR-1=0; CR-2=0; MR-1=546.6; MR-2=0	67	917.0±1.0	16.0±0.1	0.000 ± 0,001**
EP-1=EP-2=700.0; CR-1=0; CR-2=553.6; MR-1=MR-2=0	67	917.0±1.0	16.0±0.1	-3.90 ± 0,16
EP-1=EP-2=0; CR-1=700.0; CR-2=0; MR-1=546.6; MR-2=0	67	917.0±1.0	16.0±0.1	-1.90 ± 0,06
EP-1=EP-2=0; CR-1=CR-2=700.0; MR-1=546.6; MR-2=0	67	917.0±1.0	16.0±0.1	-2.65 ± 0,10
EP-1=EP-2=0; CR-1=CR-2=0; MR-1=546.6; MR-2=700.0	67	917.0±1.0	16.0±0.1	-0.70 ± 0,02
EP-1=EP-2=0; CR-1=0; CR-2=553.9; MR-1=MR-2=700.0	67	917.0±1.0	16.0±0.1	-1.43 ± 0,05
EP-1=EP-2=0; CR-1=CR-2=700.0; MR-1=MR-2=700.0	67	917.0±1.0	16.0±0.1	-3.52 ± 0,14
EP-1=EP-2=700.0; CR-1=CR-2=700.0; MR-1=MR-2=700.0	67	917.0±1.0	16.0±0.1	-7.8 ± 0,5

* the level was measured from the core bottom

** reactivity margin of critical assembly 0.61 ± 0,02 β_{eff}

Tab 2: The results of measurement of reactivity effects on the critical assembly W-20-2-0

CPS ADs position, mm	Fuel rods, pcs.	Water level, mm	Water tempe-rature, °C	Reactivity, β_{eff}
EP-1=EP-2=0; CR-1=CR-2=0; MR-1=MR-2=0	87	487.9±1.0	19.0±0.1	0.000 ± 0,001
EP-1=EP-2=0; CR-1=0; CR-2=0; MR-1=300.5; MR-2=0	87	527.7±1.0	19.0±0.1	0.000 ± 0,001**
EP-1=EP-2=0; CR-1=CR-2=0; MR-1=700.0; MR-2=0	87	527.7±1.0	19.0±0.1	-0.28 ± 0,01
EP-1=EP-2=0; CR-1=0; CR-2=700.0; MR-1=MR-2=0	87	527.7±1.0	19.0±0.1	-1.07 ± 0,03
EP-1=EP-2=0; CR-1=700.0; CR-2=0; MR-1=MR-2=0	87	527.7±1.0	19.0±0.1	-1.19 ± 0,04
EP-1=700.0; EP-2=0; CR-1=CR-2=0; MR-1=300.0; MR-2=0	87	527.7±1.0	19.0±0.1	-1.98 ± 0,07
EP-1=EP-2=0; CR-1=0; CR-2=700.0; MR-1=MR-2=700.0	87	527.7±1.0	19.0±0.1	-3.42 ± 0,14
EP-1=EP-2=700.0; CR-1=700.0; CR-2=0; MR-1=MR-2=0	87	527.7±1.0	19.0±0.1	-5.8 ± 0,3
EP-1=EP-2=700.0; CR-1=CR-2=700.0; MR-1=MR-2=700.0	87	527.7±1.0	19.0±0.1	-11.7 ± 0,8
EP-1=EP-2=0; CR-1=CR-2=0; MR-1=MR-2=0	87	440.9±1.0	19.0±0.1	-1.45 ± 0,04

* the level was measured from the core bottom

** reactivity margin of critical assembly 0.67 ± 0,02 β_{eff}

Tab 3: The results of measurement of reactivity effects on the critical assembly W-20-2-1

CPS ADs position, mm	Fuel rods, pcs.	Water level, mm	Water tempe-rature, °C	Reactivity, β_{eff}
EP-1=EP-2=0; CR-1=CR-2=0; MR-1=MR-2=0	120	481.1±1.0	17.8±0.1	0.000 ± 0,001
EP-1=EP-2=0; CR-1=0; CR-2=0; MR-1=0; MR-2=266.8	120	512.9±1.0	15.9±0.1	0.000 ± 0,001**
EP-1=EP-2=0; CR-1=0; CR-2=700.0; MR-1=MR-2=0	120	512.9±1.0	15.9±0.1	-1.40 ± 0,04

EP-1=EP-2=0; CR-1=0; CR-2=259.8; MR-1=700.0; MR-2=0	120	512.9±1.0	15.9±0.1	-0.91 ± 0,03
EP-1=EP-2=0; CR-1=700.0; CR-2=259.8; MR-1=MR-2=0	120	512.9±1.0	15.9±0.1	-1.62 ± 0,05
EP-1=EP-2=0; CR-1=0; CR-2=259.8; MR-1=MR-2=700.0	120	512.9±1.0	15.9±0.1	-1.92 ± 0,06
EP-1=EP-2=0; CR-1=CR-2=700.0; MR-1=264.5; MR-2=0	120	512.9±1.0	15.9±0.1	-4.11 ± 0,17
EP-1=EP-2=0; CR-1=CR-2=700.0; MR-1=MR-2=700.0	120	512.9±1.0	15.9±0.1	-5.7 ± 0,3
EP-1=EP-2=700.0; CR-1=CR-2=700.0; MR-1=MR-2=700.0	120	512.9±1.0	15.9±0.1	-10.9 ± 0,8

* the level was measured from the core bottom

** reactivity margin of critical assembly 0.54 ± 0,02 β_{eff}

Tab 4: The results of measurement of reactivity effects on the critical assembly W-20-2-2

Note. The "0" position — CPS AD in the top position (removed from the assembly).
The "700" position — CPS AD in the lower position (inserted in the assembly).

The reactivity margin of the critical assemblies are measured by the experimental unit “Reactivity Meter”, using the inverse kinetics method [2]. In order to exclude spatial effects of reactivity, the measurements were made using six ionization chambers, arranged at every 60° inside the side reflector of the critical assembly.

5. Calculation results

In creating the calculated model of the uranium-water critical assemblies, the following assumptions were made:

– the calculated models of fuel and absorber rods are made symmetrical;

– the calculations were made ignoring the effects of the concrete walls, ceiling and floor of the room of the critical assembly, located at a distance over 2 m away from the critical assembly, and the effects of the neutron detectors, placed about 250 mm away from the core of the critical assembly.

The calculated model of uranium-water critical assembly and the calculated model position of the fuel rod (absorber rod) in the core are presented in Fig. 6, the calculated model of the fuel rod is presented in Fig. 7, the calculated model of the absorber element is presented in Fig. 8 and the calculated model of the displacer — in Fig. 9.

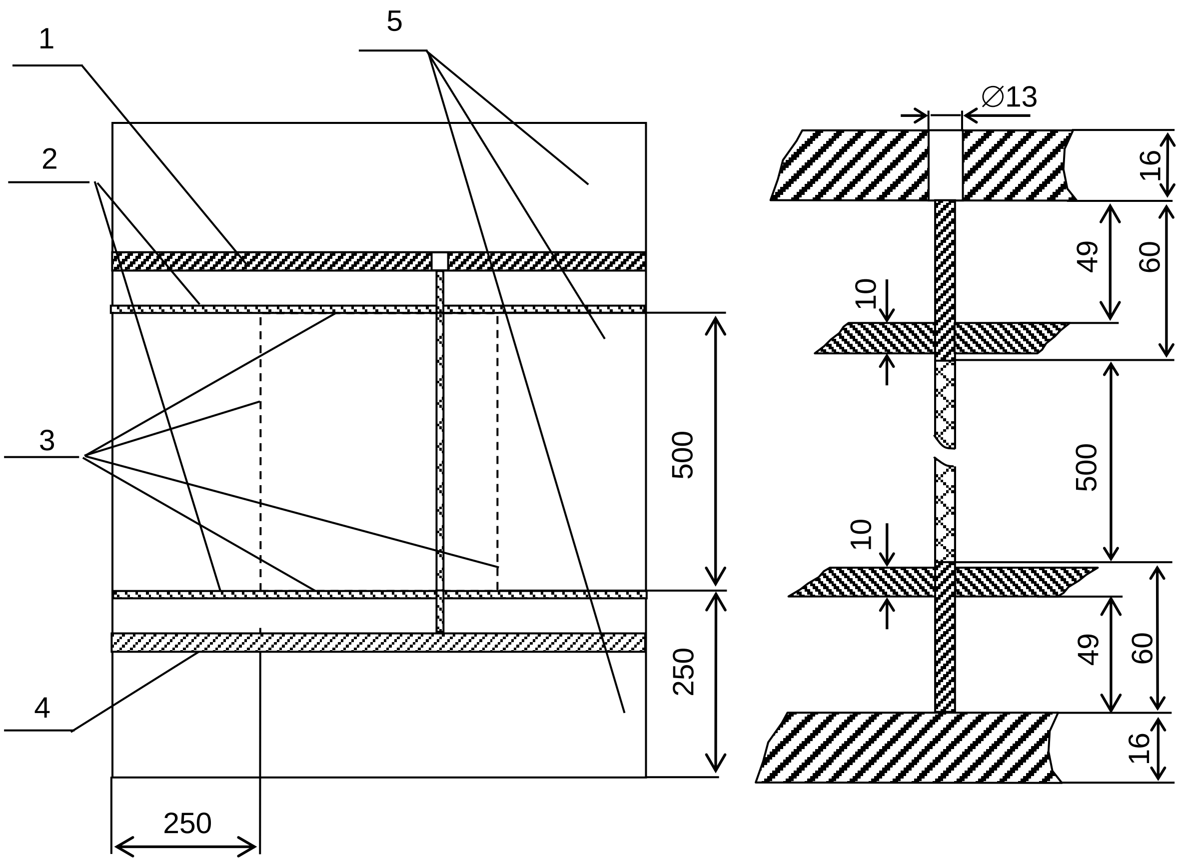

Fig 6. The calculated model of uranium-water critical assembly and the calculated model position of the fuel rod in the core:
1 – upper plate; 2 – spacing grids ; 3 – core border; 4 – support plate; 5 – water moderator

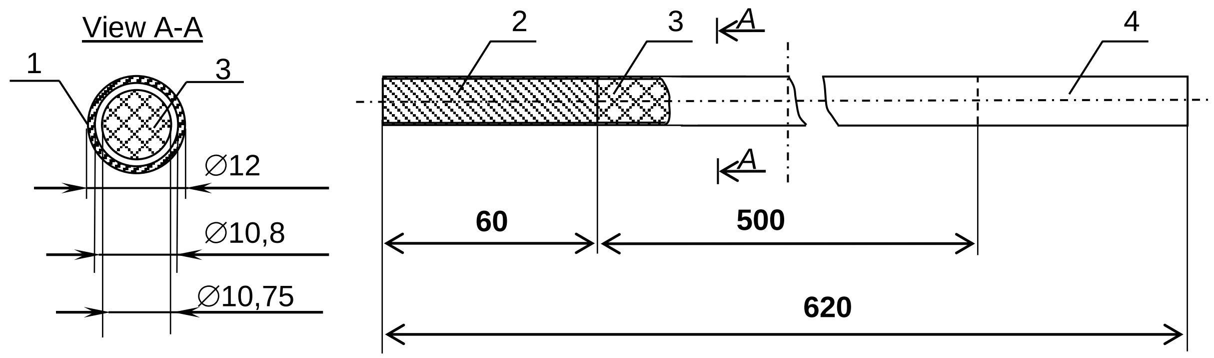

Fig 7. Calculated model of the fuel rod:
1 – cladding; 2 – upper plug; 3 – fuel core; 4 – lower plug

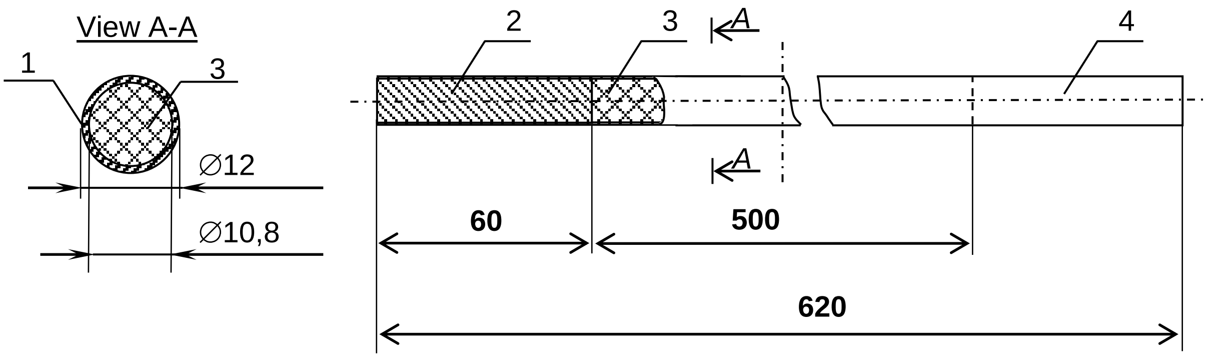

Fig 8. Calculated model of the absorber element:
1 – cladding; 2 – upper plug; 3 – absorber core; 4 – lower plug

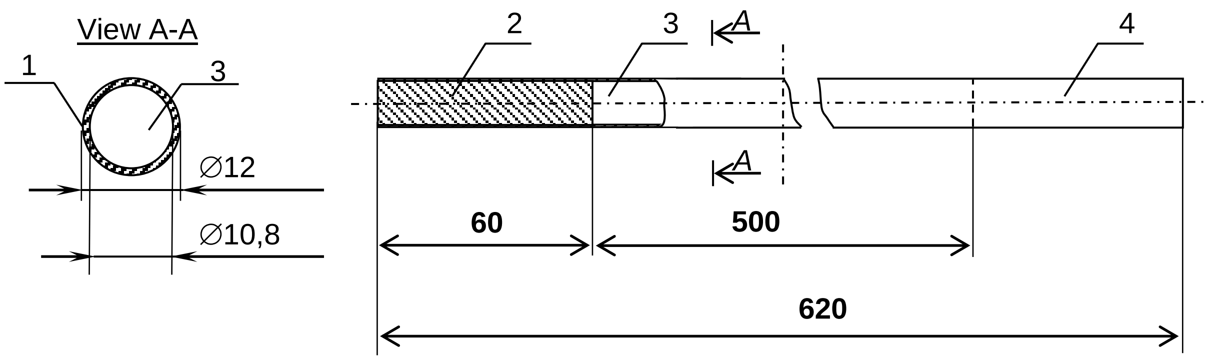

Fig 9. Calculated model of the displacer:
1 – cladding; 2 – upper plug; 3 – air; 4 – lower plug

For the estimation of experimental results, analytical models for each critical assembly have been constructed by using program codes MCNP-4c [3] with the ENDF/B-V nuclear data library and MCU-PD [4] with the MCUDB50 nuclear data library. The measured and calculated values of the neutron physical characteristics of critical assemblies are presented in Tables 5 and 6.

Critical assembly	Fuel rods, pcs.	Water level*, mm	Water tempe-rature, °C	Reactivity, β_{eff}		
				Experiment	Calculation **	
					MCNP-4c (ENDF/B-V)	MCU-PD (MCUDB50)
W-20-2-0	67	498.2±1.0	11.8±0.1	0.000 ± 0,001	0.15	0.10
	67	917.0±1.0	16.0±0.1	0.61 ± 0,02	0.68	—
W-20-2-1	87	487.9±1.0	19.0±0.1	0.000 ± 0,001	-0.02	-0.27
	87	527.7±1.0	19.0±0.1	0.67 ± 0,02	0.60	0.38
W-20-2-2	120	481.1±1.0	17.8±0.1	0.000 ± 0,001	-0.02	-0.27
	120	512.9±1.0	15.9±0.1	0.54 ± 0,02	0.60	0.38

* the level was measured from the core bottom

** the calculation is performed with completely extracted from the critical assemblies CPS ADs

Tab 5: The results of measurement and calculation of the reactivity margin
of critical assemblies W-20-2-0, W-20-2-1 and W-20-2-2

CPS ADs	Effectiveness, β_{eff}					
	Critical assembly W-20-2-0		Critical assembly W-20-2-1		Critical assembly W-20-2-2	
	Experi-ment	Calcu-lation*	Experi-ment	Calcu-lation*	Experi-ment	Calcu-lation*
CR-1	1,90±0,06	1,69	1,86±0,06	1,73	1,62±0,05	1,54
MR-1	0,70±0,02	0,71	0,96±0,03	0,83	0,91±0,03	0,80
CR-2, MR-1, MR-2	—	1,99	4,09±0,18	3,65	—	3,95
CR-1, EP-1, EP-2	—	5,61	6,47±0,36	6,09	—	5,10
All ADs	8,4±0,5	7,84	12,4±0,9	10,3	11,4±0,8	9,62

* the calculated by using program codes MCNP-4c [3] with the ENDF/B-V nuclear data library effectiveness of one or a group of CPS AD was determined by difference of calculation reactivity when CPS ADs completely removed from the critical assembly and when relevant CPS ADs is fully inserted in critical assembly

Tab 6: The results of measurement and calculation of the CPS ADs effectiveness of critical assemblies W-20-2-0, W-20-2-1 and W-20-2-2

5. Conclusions

The experimental data received at the critical facility "Giacint" on the uranium-water critical assemblies W-20-2-0, W-20-2-1 and W-20-2-2 with a core based on 19.75% fuel rods can be used at verification of computer codes by various libraries of the nuclear data.

6. References

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